



George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

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FACILITY OPERATING PROCEDURE

ED27 / STRUCTURAL AND DYNAMICS TEST GROUP

USE OF OMETRON LASER VIBROMETER FOR MODAL AND VIBRATION TESTING

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DOCUMENT HISTORY LOG

Status (Baseline/ Revision/ Canceled)	Document Revision	Effective Date	Description
Baseline		7-30-99	ED73-CDL-FOP-001 changed to accommodate reorganization and integrated document system.
Revision	A	2 April 02	Procedures added for the Laser Vibrometer Integration (LVI) system

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USE OF OMETRON LASER VIBROMETER FOR DYNAMIC TESTING

1. SCOPE

1.1 Scope. This document describes the procedure to be used when conducting a dynamic test using the *Ometron VPI Sensor* laser vibrometer and the LMS Laser Vibrometer Integration (LVI) system.

1.2 Purpose. This procedure defines the specific operating instructions of the vibrometer and LVI system.

1.3 Applicability. This procedure applies to all ED27 personnel performing dynamic tests using the laser vibrometer.

1.4 System Description. The system under test consists of the test article, *Ometron VPI Sensor*, *LMS LVI hardware* (when applicable) electro-dynamic shaker, accelerometer(s) or load cell(s), and data acquisition system.

1.5 General. The Test Engineer shall be responsible for coordination and enforcement of the document activities.

2. APPLICABLE DOCUMENTS

ED27-CDL-FOP-002	<i>Calibration of Ometron Laser Vibrometer for Dynamic Testing</i>
ED27-CDL-FOP-003	<i>HP3566/PC Data Acquisition for Dynamic Tests</i>

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3. REFERENCE DOCUMENTS

Associated Equipment Manuals

Oscilloscope

Data Acquisition System

Electro-dynamic Shaker

Ometron VPI Sensor Operator's Manual

HP 3566A/3567A Operating Reference

LMS Laser Vibrometer Integration Manual

ED27-OWI-M&V-002 Quality Records Control

ED27-OWI-M&V-003 Test Report Control

*MPG 1700.1 MSFC Industrial Safety Procedures and
Guidelines*

*ANSI Z136.1 American National Standard for Safe Use
of Lasers*

*ED27-EMA-FOP-003 HP 9000 Data Acquisition for Modal
Surveys*

*ED27-EMA-FOP-008 Cabling Schematics for the HP 9000
Computer with HP 3565 Measurement
Hardware for Modal Surveys*

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4. DEFINITIONS

- 4.1 Ometron VPI Sensor A non-contact, laser based, sensor which measures the velocity of a solid surface.
- 4.2 LMS Laser Vibrometer Integration System A hardware and software system that controls a laser vibrometer for the acquisition of three dimensional velocity measurements.
- 4.3 Electro-dynamic Shaker An electromagnetic input excitation source.
- 4.4 Oscilloscope Currently using a Tektronix TDS640A. Any general-purpose oscilloscope may be used.
- 4.5 Reference input accelerometer or load cell Any calibrated accelerometer or load cell which measures the excitation input acceleration or force.
- 4.6 Data Acquisition System (DAS) Currently using an HP3566A PC based DAS. Any general purpose DAS may be used. The DAS should have at minimum 2 inputs, one for the vibrometer output and reference accelerometer or load cell and 1 output for the excitation drive signal.

5. SAFETY PRECAUTIONS AND WARNING NOTES

The *VPI Sensor* has a laser output of no more than 1 mW and falls under the category of Class II laser products. Therefore, precautions should be taken to prevent continuous intentional viewing directly in line with the path of the laser beam. The laser beam shall not be aimed at personnel or at head height, and the beam shall be blocked or turned off when not in use.

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6. ACTIVATION PREPARATIONS

Prior to test initialization, the test engineer shall:

- a. Determine the proper excitation methods, levels, and equipment.
- b. Identify and characterize the test article fixtures and support hardware.
- c. Determine whether the test article will require surface preparation to ensure adequate laser beam return characteristics and identify the appropriate surface preparation if necessary.
- d. Ensure that proper cabling will be used for all test and measurement equipment.
- e. Determine the proper *VPI sensor* lens element to be used inside the vibrometer based on the distance from the sensor to the test article.
- f. Obtain the proper scale factors for the velocity range settings of the vibrometer and enter these scale factors into the DAS database.
- g. Check to see that the unit is current for calibration and measurement validation. If the unit is not currently in calibration refer to ED27-CDL-FOP-002, *Calibration of Laser Vibrometer for Modal and Vibration Testing*, for calibration procedures.
- h. Ensure that the *VPI sensor* unit has not been damaged or tampered with.
- i. Ensure, when in use in a test, that the LMS Laser Vibrometer Integration (LVI) hardware is properly connected to the Ometron vibrometer and the applicable HP 9000 workstation.
- j. Ensure that the test area is properly controlled to preclude the possibility of continuous, direct line of sight laser beam exposure to personnel. This may include warning signs of laser use, curtains, and/or movable tape barriers surrounding the test area.

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7. VIBROMETER ONLY PROCEDURES

- a. Set up and connect the vibrometer and DAS according to their respective reference documents.
- b. Connect the reference accelerometer or load cell to one input channel of the DAS and the *Ometron VPI Sensor* raw output signal to another input of the DAS. Connect the source excitation signal from the DAS to the electro-dynamic shaker.
- c. Turn on the vibrometer laser power supply, the vibrometer mirror power supply, and all other test and measurement equipment.
- d. Aim the laser at a specified measurement point. Using an oscilloscope, monitor the Doppler signal of the laser. Focus the laser on the measurement point until the modulation of the Doppler signal amplitude approaches 10V pk-pk or until the highest amplitude is reached.
- e. Initialize a drive point excitation through the DAS and begin frequency or time based measurements using the DAS per ED27-CDL-FOP-003 *HP3566/PC Data Acquisition for Dynamic Tests*.
- f. Upon completion of the measurement(s) for this point save the data on appropriate magnetic media. Turn off or disable drive point excitation.
- g. Repeat steps d through f until data from all the required measurement points are obtained.
- h. If three dimensional velocity measurements are to be acquired by using the LMS LVI system, refer to Section 8.
- i. Turn off the laser power supply and then turn off power supply to laser vibrometer mirrors. Power off all other test and measurement equipment.

8. VIBROMETER AND LMS LASER VIBROMETER INTEGRATION (LVI) SYSTEM PROCEDURES

- a. This section contains information that is to supplement the LMS LVI manual. It is applicable to most of the six functions of the LMS LVI system. The functions are:
 1. Laser Setup
 2. Calibration/Registration
 3. Tuning

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4. Single Point Measurement
5. Multiple Point Measurement
6. Recombination

Also information is given for LVI (LMS is not referred to for the rest of this sections) hardware setup and test article geometry definition. Procedures defined in Section 7 are still applicable and are to be used in any test.

b. LVI hardware setup procedures are as follows:

1. To interface with the LVI unit, the inline switches on the back of the vibrometer mirror power supply are set to REMOTE.
2. Use the Serial Port A on the HP 9000-750 workstation to connect the RS 232 cable from the workstation to the LVI unit.
3. Install the LVI System cable from the back of the LVI system unit to the vibrometer mirror power supply X axis BNC connector and Y axis BCN connector.
4. Prior to opening the LVI application, use the Ometron handset to focus the laser while the laser is in the neutral position. Use both the size of the laser dot (smallest size possible) and the amplitude of either of the two Doppler outputs (minimum of 500 mV peak) to obtain the optimum laser return. Inline switches have to be set to LOCAL for use of the handset. Use the soft button panel on the Ometron to select the velocity range and Auto Gain Control (AGC) if needed. AGC is always used for the low velocity range. Since RAW OUTPUT is used for acquisition of mobility frequency response functions, no decade low pass filter needs to be selected. Insure the inline switches are placed back to the REMOTE setting before opening the LVI application.

c. The following is applicable to the test article's geometry:

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1. Test article geometry cannot be exactly or close to being collinear. One or more planes of the test article geometry should have an aspect ratio as close to one as possible.
 2. The vibrometer coordinate system is defined as follows: x-y axes are in the plane defined by the face of the vibrometer, z axis is parallel to the vector the laser beam makes when it is in the neutral position. This vector is directly out of the face of the vibrometer (the x-y plane). The test article z-axis should be aligned (parallel) as close as possible with the z-axis of the vibrometer (aligned with the laser beam when in the neutral position). In most applications, especially when recombining tests, the laser beam will not be aligned with the test article's z-axis. Large angles between the vibrometer's z-axis and the test articles z-axis may in some test configurations may not be avoided.
 3. The position of the vibrometer for each of the three tests should be around the same distance from the test article and ideally should form an equilateral pyramid around the test article. Each should be around 60 degrees from each other to insure they are well separated. For each position it should be insured that the angle of the laser relative to the test article's surface at each point is not too small.
- d. The following is applicable to the laser setup:
1. In the laser setup, the geometry definition is 1mm and the view angle is 0 min. 30 sec. Geometry definition is defined in metric units only. The test article geometry can be in English units.
 2. For the fields where the horizontal and vertical conversion factors (also called parameters) are input, only one side of the expressions should have a negative value or values. The range definition is positive.

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e. The following is applicable to laser calibration/registration:

1. The angle the laser makes with the surface of the test article at each response point is usually not a concern as long as a good Doppler signal (minimum of 500 mV indicating good focus) is achieved. Acute angles (small angles with respect to the surface of the test article) at response points should be avoided as much as possible. If needed, reposition the vibrometer to avoid small angles.
2. Prior to registration of a laser position, the laser should be moved to all of the response points on the extreme edges of the test article. This is to ensure the vibrometer can "see" each point from its current location. Prior to placement of the vibrometer, a rough sketch can be made, using the straight line distance between the vibrometer and test article, to determine if the vibrometer can "see" each point on the test articles extreme edges with no more than +/-10 deg movement of the laser from its neutral position. Slightly larger angles can be used, however angles close to the maximum angles of the vibrometer (+/- 12.5 degrees) may cause problems due to nonlinear behavior of the mirror assemblies at the maximum angles. The LVI Tuning mode can also be used to determine if all the points on the test article's extreme edges can be seen by the vibrometer.
3. The array of response points used for registration should not be symmetrically distributed and should not be collinear. The array should never be coplanar. If they are, such as for a plate, just adapt some of the coordinates of these points in positive and others in negative direction to make them non-coplanar. The changes can be an order of magnitude smaller than the test article's dimensions. For the example of a 1m x 1m plate, add and subtract 1 or 2 mm from the coordinates perpendicular to the plane of the plate. The test article response point geometry itself can be symmetrical. The outer points of the array should form a geometry with an aspect ratio as close to one as possible. High aspect ratios should be

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avoided. Points near the center, extreme (outer) edges, and some in between these areas on the test article should be used. If the test article has a clear 3rd dimension (ie a 3D object) points on different "depths" should be used. Registration points should have the same geometric scale in the laser x-y plane and should be spread out equally. For most structures, at least 5 points should be used for registration. For more complicated structures, 7-8 points should be used. All response points should be contained in the volume defined by the registration points. High aspect ratio structures cause nonlinearities in the algorithm used to calculate the location of the vibrometer. In these cases, vibrometer registrations will not be accurate.

4. The coordinates calculated in the registration are the coordinates of the test article's axis system origin expressed in terms of the laser's axis system. The accuracy of the x and y coordinates (directions perpendicular to the laser beam and in the plane of the vibrometer face) is usually good. Accuracy of the z coordinate (along the line between the vibrometer and test article) is less, but this is the direction that is the least sensitive to errors. The z-axis coordinate should be between 5-8% of the measured distance between the test article's axes origin and the vibrometer.
5. After the coordinates in the registration are calculated, the check function should be used to determine the accuracy of the registration. Check first the rotation matrix for any rows or columns of zeros or very large values. If the rotation matrix is fine, then check the accuracy of the points. Values can be larger than one and numbers in the 200-300 ranges are acceptable. When checking the points used in the registration, the laser should move exactly to the same locations used for those points. When checking the other points, the laser should move fairly close to these points.
6. All response points should be checked to insure that the laser will go to the right locations during the MIMO operation. If deviations of

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several inches are seen from using the check menu for one or more points, the registration is in error and should be repeated (see next item). If the difference between the calculated and actual laser position is within 5-8% of each other, the laser should be able to be positioned at each response point. The actual laser position is determined by manually measuring the straight-line distance between the laser vibrometer and the origin of the test article's coordinate system. The tuning function should not be used to recalculate angles needed to position the laser at each response point. It should only be used when fine adjustments are needed at a response point before measurements are made.

7. If the vibrometer does not go to one or more points as seen from using the check function, then the registration needs to be repeated for that particular test. To perform a new registration, these actions can be taken to improve the calculation of the laser's position:

- a. Use additional points for registration. Additional points can be those points that the laser could not be positioned to as seen in the check function.
- b. Move the vibrometer several inches in any direction. This should be performed before any measurements are made so that the same test id can be used. If the vibrometer is moved AFTER measurements are made, then a new test with its own registration should be created so that the calculated and stored vibrometer position is the one that was used to measure the stored data.

The registration should be repeated several times if needed so that the 5-8% difference between calculated and measured vibrometer z-axis locations are obtained before measurements are made and saved to a test.

8. If the mismatch between the geometry model and the markings of the response points on the structure is determined to be large, the difference between the calculated and actual laser location can be large.

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f. The following is applicable to tuning:

1. While in the tuning mode, do not use large movements of the vertical and horizontal slider bar. Only small incremental movements should be used. For each movement of a slider bar, the laser moves to the neutral position first and then moves to the commanded position. Fast movements of a slider bar may cause the laser to fluctuate at a fast rate between the neutral position and the commanded position. To use the slider bar, click on it, move it to the desired location (angle), then release it. Wait till the laser beam is in the commanded position before moving the slider bar again. It is best to use the arrow buttons only if possible.
2. The purpose of the tuning is not to adjust all points. If the registration produces the correct laser location, the software will be able to position the laser on all response points accurately without any user interaction. Tuning is to be used to provide fine adjustments at a response point when required. It should not be used to correct for deviations seen in the check function in the registration. If deviations in the check menu are large (several inches), the registration solution is in error and should be repeated (see registration-calibration).

g. The following is applicable to Fmon-LVI-multiple point measurement:

1. All point ID's are assigned in the FMON point ID menu except for the laser channel. The laser channel point ID is assigned in the LVI software since it continuously changes from point to point.
2. If tests are to be recombined, ANGULAR CORRECTION MUST BE OFF in the MIMO mode. Each of the three tests must have the same axis and direction assigned in the MIMO. Only points that have the same direction in all three tests will be recombined. The direction doesn't matter, but +/-Z

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is usually the best choice because the distance between the laser and the test article is usually along the laser's z-axis, which should be basically parallel to the test article's z-axis.

h. The following is applicable to recombination:

1. The recombination process looks for the points in three tests that have the same axis and direction for their measurements. Only these points are recombined and placed in the list of points to be used for recombination. Only FRFs, auto power spectrums and cross power spectrums can be recombined. All or some points can be selected for recombination. For most recombinations, all points are selected.
2. Each measurement resulting from the recombination and saved in a fourth test has a sensitivity index value. Sensitivity indexes are quality indicators and they are seen in the user identification fields in the data formatter. The sensitivity index is a measure of the error amplification that is present in the recombination and they indicate how an error in the measured data propagates to the recombined data. It is different for each point and each direction of a point. Sensitivity values should be close to 1. Values at or below 6 are acceptable. Usually the sensitivity index for the z-axis is smaller than the x and y-axis because the biggest part of the measured velocity is out-of-plane. Current location refers to the response points that are fixed. Current setup is the three laser positions (three independent tests). A change in any of the vibrometer positions used in the three recombined tests or the use of a new (fourth) test in a recombination will change the sensitivity indexes.
3. A recombination of three tests can result in a strong error amplification (high sensitivity index values) even if the locations of the vibrometer in each of the three tests are calculated accurately (calculated position within 5-8% of measured) and good quality measurements are obtained. If one or more sensitivity indexes are 10 or higher, a fourth

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test is necessary. The fourth test uses a vibrometer position completely different from the locations used for the other three tests. The fourth test should be used in recombinations that have all combinations of two of the original three tests. The recombination with the lowest sensitivity values should be used. To have sensitivity values drop dramatically, a fourth test should be used.

4. Sensitivity values are based on geometrical calculations and depend on the values calculated for the three vibrometer positions. An error in one of the three vibrometer locations may produce sensitivity values lower than those obtained using three accurate vibrometer positions because these vibrometer locations (two accurate, one with error) lead to less error amplification during a recombination. However, it is more important to have accurate vibrometer registrations and good measurements for the three tests used in a recombination. The accuracy of the registrations and measurement quality determine the initial error on the data. For the most part, the influence registrations have on sensitivity values can be disregarded. If high sensitivity values are present, even though the three registrations are accurate (+/- 5 to 8% difference between calculated and measured), and the measured data in each test is acceptable, it is not necessary to use a fourth test for any new recombinations. It is more important to reduce the "initial error" on the measurements by having accurate vibrometer registrations. Therefore, the registration in each test needs to be improved as previously discussed prior to acquiring measurements. If there are sensitivity values of 10 or higher, even for accurate vibrometer registrations, a fourth test should be generated and used in additional recombinations as discussed before.

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APPENDIX A

SAMPLE

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ED27/MODAL AND CONTROL DYNAMICS TEST TEAM TEST SETUP SHEET

VIBRATION & MODAL TEST USING LASER VIBROMETER

FOR

Test Article Name

TCP #

Test Article S/N _____

Drive Point Measurement Transducer: _____ Axis: _____

Model _____ S/N _____ Scale Factor _____

Inspect the *Ometron VPI Sensor* unit for
damage or tampering _____

Connect power supply, turn on laser _____

Scan the laser to a specified measurement point _____

Focus the laser until the Doppler signal amplitudes
are maximum or 10V pk-pk _____

Enable the drive source signal _____

Record the data and save to magnetic media _____

Laser velocity range _____

Scale Factor _____

Measurement Point _____

Test Engineer

Analyst